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Analysis of surgical errors associated with anatomical variations clinically relevant in general surgery. Review of the literature

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ABSTRACT

Anatomic variations have a significant impact in general and oncological surgery, often necessitating modification of surgical techniques or leading to intraoperative complications. Difficult or variant anatomy is often cited as a significant contributing factor to injuries attributed to surgical errors. In order to investigate the influence of anatomical variations on surgical procedures, a literature search was conducted based on key words and potentially eligible articles were assessed for relevance and quality of data. In this review, we attempt to highlight some major and clinically significant abnormal anatomy that can influence the outcome of a surgical procedure, including cholecystectomy, hepatobiliary, breast and axillary, pancreatic, spleen, gastric, colon, and thyroid surgery, as well as hernia repair.

1. Introduction

Anatomical education is a mainstay of medical school curricula. However, there is evidence to suggest that the current state of anatomical education in medical school inadequately prepares students for the rigours of clinical practice. In medical school curricula, anatomy is taught through the "Vesalian" lens - that is, there is one so-called "normal" version of human anatomy reliably found in anatomical atlases and textbooks [1,2]. This practice, unfortunately, does not take the natural anatomical variations of the human form into account. Important knowledge on anatomical variations relevant to clinical practice is not discussed in anatomy courses [3]. In addition to a failure to address anatomical variations in early medical education, many anatomy courses have diminished in scope. Over the past few decades, anatomy curricula have been cut down to lighten the considerable course load of medical students; time and resources have been reallocated toward teaching students other clinical skills [2]. Furthermore, anatomy courses are a focus only in the first one or two years of medical school, with no significant follow-up as students begin clinical rotations [4]. As a result, medical school graduates are unfamiliar with anatomy, including its variations, and this unfamiliarity can eventually translate to ineptitude in analyzing a surgical plane of dissection or reading medical imaging data [3,5].

Upon analysis of data, it seems that this dearth of anatomical training early in physicians' careers may put patient safety in jeopardy. When analyzing factors contributing to technical errors during surgery, the most commonly cited obstacle is difficult or unusual anatomy [6–8]. Lien et al. reported that procedural factors, including inability to identify anatomy, was an important factor that contributed to patient injury [9].

This pattern is also evident among postgraduate institutions that preside over further training of future surgeons and other specialties. A quarter of general surgery fellowship program directors indicated that graduates had limited competencies in analyzing anatomical tissue planes [10]. In another study, only a third of residency program directors acknowledged that new residents had sufficient knowledge of anatomy [11]. Such evidence is unfortunate, particularly when studies show trainees specializing in surgery and radiology will require even more detail in their anatomical knowledge [12].

Procedural incompetence has further ripple effects in the healthcare system beyond patient injury. In an examination of legal claims involving general and vascular surgeons, poor training and insufficient professional development of skills were recurring themes that resulted in settlements [13]. Another analysis of legal claims found that

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intra-operative problems made up 50% of the reasons for a complaint that led to a successful claim; 60% of those problems were due to nerve damage and 27% for vessel damage. Clinical negligence and the ensuing legal action can also take a toll on the rapport between a clinician and their patient. This dynamic forces the physician into a defensive role to insulate themselves from the threat of legal repercussions. Unfortunately, this in turn may weaken patients' trust and overall satisfaction [14].

2. Materials and methods

This review includes an analysis of surgical errors related to the presence of clinically relevant anatomic variations during general surgery, and analysis of the literature. To investigate the above mentioned topic, a search was conducted in several leading electronic databases (Pubmed, EMBASE, Web of Science and ScienceDirect). The literature search was based on the following criteria and key words: *surgical complications anatomy, surgical errors, anatomical variations, anatomy surgical implications.* Date of publication and original language of publication were not used among the exclusion criteria. The full text articles obtained from the literature search were analyzed, and other potentially eligible studies were identified among the works cited. Any articles that could potentially meet the inclusion criteria and contain adequate, usable data were assessed by two authors.

3. Discussion

3.1. Cholecystectomy

Cholecystectomy is the most common surgical procedure performed on the abdomen, usually by laparoscopic means, and while the majority of these procedures are without complications, when mistakes happen, they can be attributed to the presence of anatomical variations [15–17]. For instance, the expected anatomy of the hepatic arterial vessels is a bifurcation of the proper hepatic artery into the right and left hepatic vessels, and in the biliary tree one would anticipate the right and left hepatic ducts to drain their respective lobes of the liver - however, these classic patterns are respectively found in only 55% and 58% of the population [17]. A crucial step in laparoscopic cholecystectomy is adequate assessment of Calot's triangle and familiarity with its associated variations in conjunction with biliary tracts and blood vessels [18–23]. Among the most serious complications of this procedure is damage to the biliary tracts and accompanying vessels [24–27]. The cystic artery (CA) may course anterior to the common hepatic duct or common bile duct, posing a risk of injury to these structures; mistakenly dissecting an accessory CA or deep CA may lead to intraoperative bleeding [22]. Anatomic anomalies in the cystic duct can be found at a rate of 4%–23%, as variations in the length of the duct, the site of confluence, a double cystic duct or complete absence altogether [28]. One additional anomaly to anticipate during cholecystectomy is the subvesical bile duct, which when injured has been shown to lead to bile leak in 1 out of every 633 operations, per one study [29]. Not only are anatomic differences significant in the development of surgical complications, but they also require conversion to the open technique [16].

3.2. Hepatobiliary surgery

Beyond cholecystectomies, anatomic variations of the biliary ducts are relevant in hepatobiliary procedures [23]. Variations of the vascular supply of the liver and biliary tree are frequent and especially significant in liver transplantation, which represents one of the most common procedures in transplant surgery [17,19,30–35]. For example, one potential obstacle in liver transplantation is variation of the liver hilus. One study reported that among liver donor candidates, variations of the hepatic artery were found at a rate of 25%, portal vein at 11%, and the bile ducts at 28% [34]. This emphasizes the importance of pre-operative planning.

Regarding the surface of the liver itself, there exist variations of the major fissures in the form of accessory lobes, all of which can serve as important landmarks for surgeons and therefore should be kept in mind when performing a procedure like a hepatectomy for the resection of a liver tumour [36,37]. One study found that out of 80 cadaveric livers, only 14 were normal; out of the other 66, 28 had abnormal fissures and 29 had abnormal lobes [36]. Although rare, one or more accessory lobes have been reported - such an occurrence is a rare congenital condition that is usually asymptomatic and discovered incidentally during laparotomy [36,37]. In some cases, however, these anomalies may present with clinical symptoms such as abdominal pain and decreased liver function [37]. Preoperative imaging tests may be useful for surgical planning in the event of accessory hepatic lobe torsion.

During a resection of a Klatskin tumor (hilar cholangiocarcinoma) on a patient with presumed normal biliary anatomy, a team of surgeons encountered the following anomaly: a 7.5 cm-long extra hepatic right duct, a 5 cm-long left duct, and a cystic duct that directly joined the distal end of the right duct [20]. These structures came together in a trifurcation that began at the common site of the origin of the cystic duct. The proximal common bile duct was missing. The extra long hepatic ducts allowed the team to obtain tumour-free margins after resection and avoided extensive dissection of the liver. In this case, an anatomic variation led to a favourable outcome thanks to the sufficient expertise of the surgeons who were able to recognize such an opportunity.

One particularly notable variation in the vicinity of the liver is the arc of Buhler, a rarely reported variant that was first described over a century ago, and involves an arterial anastomosis between the celiac trunk and the superior mesenteric artery (SMA) [38,39]. Such an anatomic variation can have important implications for endovascular procedures of the liver, including chemoembolisation, during which ligation or occlusion of the gastroduodenal artery (GDA) can be performed before administration of continuous direct intrahepatic chemotherapy for liver tumors via infusion pump [40].

3.3. Pancreatic, gastric, and spleen surgery

The arc of Buhler is relevant not only to the liver and biliary tree, but to the upper abdominal viscera. Its presence may have implications for Whipple's procedure, gastrectomy, pancreatectomy [41]. Although its incidence is 3.3% of the population, the arc of Buhler may prove useful as collateral flow in the event that the celiac trunk or SMA is occluded [39]. Thus, the abdominal viscera supplied by those arteries may be protected in cases of mesenteric ischemia [38,39]. In three cases described by one study, the authors describe the importance of the arc of Buhler and its relation to the celiac trunk, SMA, and GDA. In each case, the presence of the arc of Buhler had implications for the blood supply of the liver, stomach, pancreas, duodenum and spleen - and the ligation or occlusion of one of the arteries in this system could potentially compromise the arterial supply to any or all of these organs [41]. Thus, potential arterial vascular disasters can be prevented with a thorough knowledge of anatomical variations and proper pre-operative planning.

In pancreatectomy and pancreatoduodenectomy, complications and errors can be mitigated by a thorough knowledge of the surrounding vascular and potential aberrations [31,42]. Even a landmark as familiar as the celiac trunk (CT) in subject to anatomic variation; the most common branching pattern is the classic trifurcation into the common hepatic artery (HA), splenic artery (SA), and left gastric artery (LGA). The classic CT trifurcation has been described in both cadaveric and radiographic studies at a frequency of 82–97% [43–45]. Among the anomalies that have been found, there exists a celiaco-mesenteric trunk (1.1–1.4% frequency), a hepatosplenic trunk (2.8%), hepatomesenteric trunk (1.7%), and gastrosplenic trunk (1.4%). One unique case study describes a rare combined anomaly in which the CT bifurcates into the CHA and SA, while the LGA arises directly from the abdominal aorta and eventually bifurcates into the right inferior phrenic artery and an accessory left hepatic artery [46]. A detailed knowledge of the CT and its variations is crucial during pancreaticoduodenectomy, as well as liver transplants and hepatic artery infusion chemotherapy. In addition to familiarity with anatomical variations, complication-free pancreatectomy involves wide exposure of the pancreas, safe mobilization of the portion meant for resection, and sufficient skills to manage potential complications of pancreatic surgery [31]. Among the most relevant vascular variations during these procedures are an accessory right hepatic artery, and an accessory or displaced common hepatic artery; both these vessels arise from the SMA [38]. Proper identification of these aberrations is necessary to avoid intra- and post-operative complications during pancreatoduodenectomy, such as accidental ligation of the accessory right hepatic artery (RHA) and displaced common hepatic artery (CHA). It is recommended that ligation of the GDA be performed only after the retropancreatic dissection. Further precautions may include pre-operatively clamping arteries meant for ligation and controlling the blood flow after ligation has been completed. The variation of the vasculature may also alter the landscape of the area to be resected. The surgeon may be faced with the dilemma of choosing between achieving tumour-free margins and compromising vascular integrity. Accidental ligation may also lead to pancreatic or biliary anastomotic leak, with a possible elevation in postoperative hepatic enzymes [42,47]. Lastly, damage to an aberrant artery may lead to unexpected bleeding and intraoperative blood loss [42].

Beyond vasculature, pancreatoduodenectomies may be complicated by other aspects of aberrant anatomy. One study proposed that variations in the morphology of the main pancreatic duct contribute to the outcome of pancreatic anastomoses [48]. These aberrant ducts can be missed and left undrained or blocked after surgery, contributing to the development of post-operative pancreatitis or pancreatic fistulas. Smaller aberrant ductules may be left to drain outside to the pancreas, leading to a pancreatic leak.

Gastrectomies may also be plagued by vascular variations, with the celiac artery having a variation rate of about 33%, and variation of the hepatic artery existing at a rate of about 28% [49]. Such additional difficulties can culminate in intra- and post-operative complications. Studies have shown that operative time and blood loss were elevated in those patients with variations in their celiac artery [47,49]. When performing a radical D2 lymphadenectomy for the treatment of advanced gastric cancer, a missing CHA may lead to difficulty tracing metastases to lymph nodes. The spleen is another organ worth discussing for its anatomic variations. During a splenectomy, a surgeon should be aware of the possibility of encountering an accessory spleen as a common anatomic variant, which can be found in about 15% of the human population [50,51]. Failure to remove all portions of the spleen can be especially harmful in patients affected by immune thrombocytopenia, in which refractory symptoms can persist. In cases of intra-abdominal hemorrhage, the surgeon must be able to recognize such an accessory spleen, and remove it should it be the source of bleeding. An extremely rare, but dangerous, complication of splenectomy is gastric necrosis, appearing in less than 1% of patients who undergo splenectomy; despite its scarcity, studies report a mortality rate of 60% among these patients [51]. The authors speculate that this necrosis was due to the ligation of short vessels that were not associated with the expected anastomoses between arteries of the gastric region.

3.4. *Colon surgery*

The vascular network of the colorectal system is so richly complex that it would be unfeasible to exhaustively describe it and all its variations in this review. Nevertheless, for surgeons, a detailed familiarity with the anatomic features, including possible variations and consequences of ligating a certain vessel, can help minimize the number of operative complications, particularly in obese patients [35,52–54]. In a study analyzing critical errors in technical performance of laparoscopic colorectal surgery, failure to identify correct anatomy represented 6.8% of all errors [55].

As mentioned above, although the variations of the entire colonic vasculature are extensive, some blood vessels and their corresponding variations are worth discussing in further detail. In particular, there has been particular interest in studying the variation of the branching pattern from the SMA, superior mesenteric vein (SMV), inferior mesenteric artery (IMA) and inferior mesenteric vein (IMV) [35,40,56]. Absence of the SMA has been reported, conferring important implications for surgeons operating in the region of the rectum and sigmoid colon - if the IMA were ligated, there would be no compensating anastomosis from the SMA and the blood supply to the structures derived from the middle and posterior intestine would be severely compromised [35,53]. Although rare, absence of the SMA in infants is the suspected cause of congenital duodenal atresia, contributing to poor digestion and absorption in the middle intestine. Another study reaffirms the difficulty and importance of anatomical variation in the vasculature of the lower abdomen. In identifying six unique variations of feeder vessels to the splenic flexure, the authors point out that should the IMA be ligated during bowel resection and lymph node dissection, this may result in disrupted blood supply in two of the identified vascular patterns [40].

Another area of interest is the vasculature of the right colon, which represents a complex area of anatomic variation that must be managed with care during laparoscopic procedures or else risk vascular complications [54,57–59]. For instance, the gastrocolic trunk of Henle (GCT) is composed of the joining of the superior right colic vein and right gastroepiploic vein which empty into the SMV on the inferior aspect of the pancreatic neck, and its presence and corresponding tributary vessels are highly variable. The area of the right colon is further complicated by the surrounding lymph nodes that must be dissected in cases of hepatic flexure or transverse colon cancer; failure to recognize an anatomic variation during lymph node dissection may lead to injury and massive hemorrhage [54,57].

3.5. *Inguinal hernia repair*

The Lichtenstein method for inguinal hernia repair is one of the most commonly used techniques around the world [60–62]. Despite the many advantages of this technique in the surgical correction of inguinal hernias, it carries, like any surgical procedure, a certain set of complications, the most frequent of which is persistent postoperative pain. This complication, defined as pain that persists for at least three months after the procedure, may affect as much as 30% of patients undergoing inguinal hernia repair and presents a significant problem for patients and surgeons alike [63–66]. It is most often the consequence of nerve damage in the inguinal region, whether during intraoperative injury to nerve tissue or compression of nerves by the mesh [61,63,67]. For this reason, identification of the relevant nerves in the clinical setting is of the utmost importance. The surgeon should take extreme care and attention when performing this procedure, especially since the course of the nerves in this region may be variable [63]. According to some studies, only about 20% of patients possess sensory innervation from the ilioinguinal and iliohypogastric nerves according to the classical anatomical distribution [63,68]. Another important consideration in inguinal hernia repair is the variation of the lateral femoral cutaneous nerve (LFCN), in which an early bifurcation or, even a trifurcation or quadrifurcation, can be at risk for iatrogenic injury [69]. Even the less invasive laparoscopic hernia repair can be complicated by variable anatomy, and success in this area is dependent on a sound anatomic knowledge of abdominal aponeurosis, especially the posterior rectus sheath [70]. Furthermore, the surgeon must be mindful when suturing the mesh into Cooper's ligament, which may contain a vascular structure called the corona mortis; disruption of this network of blood vessels may result in life-threatening hemorrhage [71].

3.6. Thyroid surgery

The most common iatrogenic complication during thyroid surgery is injury to the recurrent laryngeal nerve (RLN), owing to its variant anatomical course that facilitates visual misidentification [72–75]. The variations of the RLN that may cause difficulty for surgeons include extra laryngeal branches, distorted branches, intertwined branches that weave through the RLN itself and the inferior thyroid artery, as well as non-recurrent laryngeal branches [72,76,77]. Other nerve connections that surgeons should be cognizant of are Galen's anastomosis and the arytenoid plexus [75]. Although RLN injury has an incidence rate of 0.5–5%, patients report post-thyroidectomy voice changes at a rate of 51.6% [75]. Vocal cord paralysis and hoarseness are the result of unilateral RLN injury, but a bilateral injury can lead to more concerning sequelae, such as dyspnea and obstruction of the larynx [73]. Close attention and care to this area, intraoperative identification of the RLN, and knowledge of anatomical variations in the vicinity of the thyroid can help minimize such iatrogenic injuries incurred during surgery [73,75,78,79]. The thyroid itself is also subject to frequent anatomical variations; accessory lobes or tissue can be found superiorly, inferiorly, externally and posteriorly relative to the gland [80,81]. Such an accessory lobe may be a source of pitfalls during preoperative diagnosis on scintigraphic imaging for thyroidectomies [81]. For instance, an accessory thyroid gland located at the carotid bifurcation may present as a carotid body tumor [81]. Rarely, thyroid tissue within the tracheal lumen could be a cause of upper respiratory obstruction, and must be investigated to determine if it is ectopic tissue or a malignant invasion of the trachea [81]. Although considerably smaller than the thyroid itself, the parathyroid gland is a structure that must be preserved during thyroid surgery due to the dangerous complication of hypocalcemia, which can be avoided by careful surgical technique and excellent knowledge of its position relative to other cervical structures [82,83].

3.7. Breast and axillary surgery

The region of the axilla, as it relates to increasingly common surgical procedures such as breast reconstruction, lymph node dissection for breast cancer, and axillary bypass surgery, is subject to anatomical variations that can cause confusion and lead to iatrogenic injury [84,85]. A structure of particular interest in this region is the axillary arch (AA), also known as Langer's arch, a muscular or fibromuscular slip that extends from the latissimus dorsi (LD) muscle to insert under the surface of the pectoralis major muscle in the posterior axilla and in one meta-analysis had a prevalence rate of 5.3%, representing a common anatomic variation [86]. Surgeons should be aware of the AA as it may obstruct axillary lymph nodes from view, and failure to adequately dissect all axillary lymph nodes may lead to recurrence of breast cancer [84,86]. The AA has also been found to cause entrapment of the axillary vein and musculocutaneous, median, and ulnar nerves, even if in most cases its presence is asymptomatic [87]. Further complications caused by the presence of the AA include mistaking the variant for the LD and incorrectly dissecting into a supra-axillary plane, leaving the axillary artery and brachial plexus vulnerable to injury [84,85]. Beyond the AA, variation in the axillary region can be attributed to the origin and branching pattern of the intercostobrachial nerve (ICBN), putting it at risk of injury during surgeries for the treatment of breast cancer and potentially leaving patients with post-operative pain and paresthesias [88]. During breast reconstruction surgery, the internal thoracic vessels are used as recipient vessels, but variation in their anatomical course and structure may render them unusable for the procedure, necessitating an alternate strategy [89].

4. Conclusion

The goal of this review was not to exhaustively identify every significant anatomical variation in general surgery procedures - such an endeavour would be worthy of several separate publications. Rather, we set out to highlight the immense influence of anatomical variations on the successful outcome of a variety of surgical procedures. Failure to identify variant anatomy is a commonly cited technical error in surgical injuries, even among experienced surgeons [55,90,91]. This gap in technical expertise must be addressed, as these injuries lead not only to adverse events in patients, but to malpractice claims. Anatomy dissection courses with a focus on teaching surgical trainees the variability of human morphology could potentially close this gap, along with taking advantage of pre-operative imaging techniques to verify morphology. Such preemptive interventions may positively impact surgical outcomes, minimize need for reoperation, and improve patient satisfaction, relieving the burden of medical errors from the healthcare system.

Credit author statement

Katarzyna A. Kowalczyk: Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Visualization, Writing – review & editing; Adrianna Majewski: Writing – original draft & editing.

Declaration of competing interest

None declared.

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